VOLUME X. NUMBER 10

THE JOURNAL
OF
THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

DEVOTED TO THE ADVANCEMENT OF ASTRONOMY AND ALLIED SCIENCES

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PUBLISHED MONTHLY

December, 1916

PRINTED FOR THE SOCIETY
TORONTO: 198 COLLEGE ST.
FOREIGN AGENTS: WILLIAM WESLEY & SON
28 ESSEX ST., STRAND, LONDON.

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Communications regarding Library matters should be addressed to the Librarian.

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PLATE XVII.

THE FIRST OBSERVED TRANSIT OF VENUS

From a painting by W. R. Lavender, in the possession of G. Napier Clark, Edinburgh.

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SKETCH OF THE LIFE AND WORKS OF REV. JEREMIAH HORROX.*

BY G. NAPIER CLARK.

THE village of Hoole, which lies nine miles directly E.N.E. of Southport, is proud of the fact that the Rev. Jeremiah Horrox, "a prodigy for his skill in astronomy," taught its children and ministered to its people, though only for a brief period between June, 1639, and July, 1640. It was while living there in 1639 that he, at the youthful age of 20, corrected the ephemerides of the astronomers Kepler and Lansberg, for the planet Venus, and proved the accuracy of his own calculations by observing, within two minutes of the time he reckoned, that planet on the face of the sun.

A church had existed at Hoole, or Much Hoole, from the fifteenth century, but the present edifice, dedicated to St. Michael, of which Horrox was curate, was built in 1628. It was in those days simply a Chapel of Ease to the ancient Church of Croston, which is distant about three or four miles. A stone tower was raised in 1720, and a chancel added in 1824. In 1857 an appeal

* In this JOURNAL, vol. ix., p. 271, 1915, appeared a paper on Horrox, by Dr. A. D. Watson, which aroused considerable interest. This sketch will also be found very acceptable.—Editor.

was made by the Rev. Robert Brickell, Rector of Hoole, to the Lancashire public and to scientists generally for subscriptions to commemorate the name of his distinguished predecessor, with the result that in 1859 a Horrox Chapel, with a memorial window, was added to the church, and the old pulpit from which he preached was restored. A marble tablet also was placed in the church by the clergy, and a clock in the tower by the parishioners.

The story of his short life, from the few details which can now be gathered, is interesting and pathetic. He was born at Toxteth, near Liverpool, in 1619, where his father was a small farmer. As his parents, relatives, and neighbors were strict Puritans, he passed his childhood amidst the prevailing moroseness and austerity of the time. He began his studies at an early age, and at 14 he was sent to Emmanuel College, Cambridge, where he conceived a passion for the study of astronomy. He writes at this time, "It seemed to me that nothing could be more noble than to contemplate the manifold wisdom of my Creator as displayed amidst such glorious works; nothing more delightful than to view them no longer with the gaze of vulgar admiration, but with a desire to know their causes and to feed upon their beauty by a more careful examination of their mechanism." But the difficulty of studying mathematics and astronomy at that time was great. He had no teacher and very few books, and the success he gained he owed to his own genius and determination. He relates his difficulties in the following touching words:—

"There were many hindrances. The abstruse nature of the study, my inexperience and want of means dispirited me. I was much pained not to have any one to whom I could look for guidance, or indeed for the sympathy of companionship in my endeavors, and I was assailed by the languor and weariness which are inseparable from every great undertaking. What, then, was to be done? I could not make the pursuit an easy one, much less increase my fortune, and least of all, imbue others with a love of astronomy; and yet to complain of philosophy on account of its difficulties would be foolish and unworthy. I determined, there-

fore, that the tediousness of study should be overcome by industry; my poverty, failing a better method, by patience; and that instead of a master I would use astronomical books. Armed with these weapons I would contend successfully; and having heard of others acquiring knowledge without greater help, I would blush that anyone should be able to do more than I. Always remembering that word of Virgil's

'Totidem nobis animæque manusque.'"

During his stay at College he read and studied the lives and works of Tycho Brahe and Kepler. He says he experienced great delight in thinking of the fame of these excellent masters in the science, and that he would seek to emulate them in his aspirations. Having heard the Tables of Lansberg, the Belgian astronomer, highly praised, he procured a copy with great difficulty, devoted the whole of his energies to its perusal, and recomputed these ephemerides for several years. Afterwards, when he found how erroneous these tables were, he regretted the misapplication of his time; but the time was not really misspent, for it led him in the future to rely upon his "own eyes to observe the position of the stars in the heavens."

In 1636 he became acquainted with William Crabtree, of Broughton, Manchester, an astronomer and "famous mathematician." This acquaintance ripened into an affectionate friendship, for afterwards he calls him "my very great friend," and "my most dearly beloved friend." And Crabtree, on the other hand, called Horrox his "second self." To this friendship we owe everything which is known of the works and discoveries of Horrox, for all his papers were lost with the exception of those treasured and preserved by his friend.

After spending three years at Cambridge he returned to his father's house at Toxteth. We gather that there he not only met with no sympathy but even encountered opposition in the pursuit of the study which had now possessed his mind and soul. But, although discouraged and opposed, he steadily held on his way. To his beloved friend Crabtree he communicated his thoughts

and unburdened his soul. He told him of the trials and troubles he had with his instruments, of the contrivances he employed to assist him in his observations, and complained of his ill equipment generally. About this time he succeeded in making a telescope of such power as to show spots on the sun, the same instrument with which he observed the eclipse of the sun in May, 1639, and the transit of Venus in November of the same year. In June, 1637, he obtained the Rudolphine Tables published by Kepler; and in the same year he wrote a dissertation defending the Keplerian astronomy against the hypotheses of Lansberg. With the aid of Kepler's tables, which he amended, he discovered the inequality of the mean motions of Jupiter and Saturn. The acceleration of the mean motion of Jupiter seemed to him to amount to 1′ for every ten years, and evidently, from the words he uses, he thought this inequality to be *periodic*. The mean motion of Saturn, on the other hand, he found was retarded. He says these phenomena would occasion him greater annoyance were it not that there was some consolation in being the first who discovered them.

He also gave his attention to the movements of Comets, and after a considerable amount of thought and study he eventually came to the conclusion that Comets *move in elliptic orbits (or nearly elliptic orbits), and that they are carried round the sun with a velocity which is probably variable.*

In March, 1637, he and his friend watched an occultation of the Pleiades by the Moon, and they noticed that as the stars approached the dark limb each vanished instantaneously. From this phenomenon Horrox was the first to *remark that the apparent diameters of the stars must be extremely small, indeed that they must be mere points.*

It is surprising that one so young, and with such poor equipment, could not only observe with accuracy, but could draw such remarkable deductions from the facts he discovered.

The continued use of the writings of Tycho and Kepler afforded him on the one hand much gratification, and on the other an incentive to renewed application. These great masters had

devoted much time to the motions of the moon. Tycho had discovered its third inequality, *the Variation*, and its fourth, *the Annual Equation*: the latter was discovered independently by Kepler. In his calendar for 1598, Kepler stated that the solar eclipse of that year would be total. It turned out, however, that not only was it not total, but that it was an hour and a half later than he predicted. On thinking over these discrepancies and trying to account for them, he suggested that the moon might be retarded in its motion by a force emanating from the sun which would be greatest at perihelion, when the earth and the moon would be nearer the sun than they were at aphelion. He afterwards, however, rejected this theory. Horrox pondered over these theories and discoveries. He corrected the Annual Equation to 11′ 16″ which is only 4″ more than it is now known to be. Tycho made it 4′ 5″ only. He closely observed the motions of the moon, and tried to find an explanation of its marvellously intricate orbit and the inequalities of its longitude. His intense reasoning powers were concentrated on these phenomena until at last he was able to unravel the tangled skein of the moon's orbit. Kepler had found that Mars, the earth, and other planets moved in elliptic orbits; but the solution of the shape of the moon's orbit had puzzled him. To this young philosopher was left the glory of the discovery that the moon too moved in an elliptic orbit, with the earth in one of its foci; and that its apsides had a considerable progressive motion which he attributed to the *disturbing influence of the sun*. It was this movement of the apsides which, to a great extent, concealed the shape of its orbit. From this discovery his sagacity led him to an explanation of the second inequality, *the Evection*, which, he pointed out, depended upon the position of the apsides with regard to the position of the sun and the earth.

These discoveries alone entitle him to a niche in the Temple of Fame. But he was yet destined to give to the world thoughts which were to fall as seed in the minds of others, to germinate and in time to bear a glorious harvest.

Many vague and fanciful theories of a magnetic or attractive influence issuing from the sun which acted upon the planets, and upon the earth and the moon, had been held by philosophers from an early period. Kepler announced the principle of gravitation, but could not explain why the attracting bodies always kept apart; why they did not approach nearer to one another and ultimately unite. He tried to overcome the difficulty by saying that the sun rotated from west to east and threw out magnetic fibres which drew the planet in a direction transverse to the line joining it and the sun. Recognizing the weakness of his theory, he tried to fortify it by adding "So is the will of God."

In searching into the cause of these curvilinear orbits, it is convenient to think of the motion of the planet or satellite as the resultant of two motions, the one by which the body has an original motion of its own, and the other by which it is drawn towards its centre of gravity. Horrox was the first to conceive this idea. He wrote to his friend Crabtree that he had been meditating upon the principle by which planets moved in oval orbits. He rehearsed Kepler's theories, and said that these would not satisfy him. "It is most true that the will of God is the cause of all things, but resting on generalities is the death of philosophy. I must have another cause for that oval figure. It appears to me, however, that I have fallen upon the true theory, and that it admits of being illustrated by means of natural movements on the surface of the earth, for Nature everywhere acts according to a uniform plan, and the harmony of creation is such that small things constitute a faithful type of greater things. A weight is thrown into the air: at first it rises quickly, then moves slowly, until at length it is stationary and falls back to the earth with a velocity which continually increases. It thus describes a libratory movement. This movement arises from the impetus in a right line which has been imparted to it by your hand together with the magnetic influence of the earth." He further illustrated the movements of the planets by showing that if a weight suspended

by a long cord from a fixed point be drawn aside, and whilst it is released, a tangential impulse be given to it, it will not only describe an ellipse, but its apsides will advance slowly in the direction of its motion. By thus appealing to the smaller things in nature he was able to interpret the mystery of the greater things. He was able to show how a planet preserved its elliptic orbit, how its apsides moved, and in the case of the lunar orbits how the apsides moved so rapidly by the disturbing influence of the sun. Thus he became the forerunner of Newton. He rendered that great genius material help in the establishment of his laws of gravitation, and Newton in return erected an everlasting memorial to the genius of the poor curate of Hoole, by preserving his name to all generations in his monumental work, the Principia.

In June, 1638, he had the joy of communing in person with his friend and "second self" by visiting him at Broughton. On the 22nd of May, 1639, he observed most clearly an eclipse of the sun through his telescope.

In June of that year he went to Hoole, where he had accepted duty as curate at a stipend of £40 per annum. There, although he had "daily harassing duties" and little leisure, he calculated the positions of the planets from tables drawn up by himself, and late in the autumn he found that, contrary to the predictions of Kepler and Lansberg, Venus in its conjunction *would* cross the disc of the sun. On 26th October he advised Crabtree of the transit which would take place on the 24th November, and begged him most earnestly to use his telescope with attention, and especially to note the diameter of Venus, which, according to Kepler, was 7′, according to Lansberg 11′, but, according to his estimate, scarcely greater than 1′. He now carefully prepared for what he called the "Uranian banquet." Following the plan adopted by Gassendi in viewing the transit of Mercury eight years previously, he fitted up his telescope so that in a darkened room he could receive the sun's rays through it, and project the image of the sun on a sheet of paper. This paper he prepared by drawing upon it a circle of nearly six inches diameter. The

circumference he divided into 360°, and the diameter into thirty equal parts. He carefully focussed his glass, and arranged the distance of his paper so that the sun's image should exactly fill the circle. He now awaited the event with eager expectancy. The memorable day arrived, but unfortunately, as it happened to be a Sunday, he could observe only between the intervals of his services. "I watched carefully," he says, "from sunrise till nine o'clock, and from a little before ten till noon, and at one in the afternoon, being called away in the intervals to business of the highest importance, which for the sake of these ornamental pursuits I could not with propriety neglect." After the usual two hours service in the afternoon, at a quarter past three, he hastened from church to his darkened room. There he nervously and anxiously moved his telescope and the graduated circle into the path of the sun's rays. "At this time," he writes, "an opening in the clouds, which rendered the sun distinctly visible, seemed as if Divine providence encouraged my aspirations, when, oh, most grateful spectacle! the realization of so many ardent desires! (ecce gratissimum spectaculum et tot votorum materiem!) I perceived a new spot* of unusual magnitude and of perfectly round form that had just wholly entered upon the left limb of the sun, so that the margins of the sun and of the spot coincided with each other, forming an angle of contact. I immediately lost all doubt that this was the shadow of Venus, and applied myself to the careful observation of it." He had only half-an-hour to do so, for the sun set at 3.50, but he made good use of his limited time. He found by means of the graduations on his circle that the planet had entered the eastern limb of the sun at 62° 30′ from the southern point of the vertical diameter. He carefully watched its progress, and at 3.35 and at 3.45 he estimated the distance of its centre from that of the sun. By means of the divided diameter of his circle he very accurately estimated the diameter of Venus

* He had for two or three days been watching a group of sun spots.

HOOLE CHURCH
From a photograph by D. E. Benson

CARR HOUSE, MUCH HOOLE
From a copyright photograph by C. Woodall

not to exceed 1′ 12″.* At Manchester, unfortunately, clouds prevailed, and Crabtree, although permitted to see the transit, was so transfixed with joy and amazement at the wonderful sight, that before he could recover himself clouds again obscured the spectacle.

So it happened that these two young friends had the privilege of viewing a phenomenon which had never before been seen by man, and a recurrence of which could not again take place until after a lapse of 122 years.

In an ode apostrophising the departing sun with Venus, the "beauteous Queen," Horrox wrote:—

> "Thy return
> Posterity shall witness; years must roll
> Away, but then at length the splendid sight
> Again shall greet our distant children's eyes."

During the remainder of his stay at Hoole he was engaged in writing an account of the transit under the title "Venus in sole visa."

About July, 1640, he returned home, probably on account of ill health. From there he wrote to Crabtree of the uncertainty of his affairs, or harassments and "perpetual annoyances." In the midst of these troubles, however, he began a systematic study of the tides, and told his friend that he had gathered many interesting facts which had not before been noticed, and that he hoped before long to arrive at some valuable conclusions respecting their nature and cause. Unfortunately, all his papers regarding these investigations were lost.

Later in the year he wrote that he would long since have "hastened" to his friend but that he was prevented by a "great

* The house pointed out by tradition as the house in which Horrox lived whilst at Hoole is Carr House, about half a mile south of the church, a quaint and solidly built edifice of brick and stone, with projecting porch and gable facing the south. The late Rev. R. Brickel was of the opinion that the centre room on the first floor, with the recessed window over the porch, was that in which Horrox saw the transit.

necessity." In December, he thinks he might be able to visit him at Christmas, and in his last letter, dated 19th December, 1640, he says that he could at length fix Monday, 4th January, 1641, as the day of his visit, and that he might expect him on that day "if nothing unforseen should occur." Alas! that meeting to which both had looked forward with exquisite delight was destined never to take place, for Horrox died suddenly on 3rd January, the day before his intended visit. He had only entered the 23rd year of his age. Crabtree felt the loss of his friend acutely, and on the back of this letter, after recording his loss, added, "Thus God puts an end to all worldly affairs. I have lost, alas! my most dear Horrox. Hinc illæ lachrimæ! Irreparable loss!"

In meditating on the scientific career of Horrox, the span of which could scarcely have measured eight years, we are amazed that he attained such eminence. He was burdened with poverty and ill health, dispirited for want of sympathy and companionship, hindered for lack of books, crippled for want of implements, and he went astray because he had no one to help him. But his patient persistence, his courage, his self-reliance, and his great genius overcame these obstacles. Step by step he steadily trudged on his rugged way towards a land which was revealed to him as being full of promise, but which he was not to be permitted to enter. He knew the richness of that land, but like Moses he could only view the fair expanse from afar. The height he reached has been gauged by Robert Grant in his History of Physical Astronomy: "He (Horrox) unquestionably arrived at a greater appreciation of Kepler's discoveries than any of the successors of that great astronomer had hitherto done; while the sagacity and originality of his views on various points relating to Astronomy, his fertile and glowing imagination, and his ardent enthusiasm in the pursuit of science, all seemed to foreshadow a career of uncommon brilliancy, which a premature death unfortunately soon brought to a close. Even his brief labors, however, have assured to him a reputation which will live imperishably in the annals of science. By his own countrymen he cannot fail to be

regarded with peculiar interest, as the morning star of a galaxy of men of genius, who continued for about a century to adorn these isles by their successful cultivation of the Physico-Mathematical Sciences."

EDINBURGH,
SCOTLAND.

NOTE ON THE PAINTING, BY W. R. LAVENDER, OF THE FIRST OBSERVED TRANSIT OF THE PLANET VENUS (PLATE XVII.).

The painting represents the first observed transit of the planet Venus.

This historic observation was made at the village of Much Hoole, near Southport, on 24th November, [o.s.] 1639, by the Reverend Jeremiah Horrox, whose age at that time was about 20.

As no description or portrait of the observer is in existence the representation of him in the painting is purely imaginary.

It is now impossible to know exactly what contrivances Horrox used in order to make his observation successful, but by carefully reading the treatise he has written on the subject, "Venus in Sole Visa," his letters to his friend Crabtree, and the astronomical works of that period, it is possible to imagine an apparatus which could not differ very much from that which he actually used.

By the aid of friends this youthful astronomer had constructed a telescope with which he examined the eclipse of the sun in May, 1639, and which he says was sufficiently powerful to show even the smallest spots upon the sun. This instrument would have a non-achromatic convex object glass of perhaps one inch or one inch and a quarter diameter, whose focal length would be somewhere about five feet, and its eye piece would consist of a concave lens.

He describes the preparations he made for the important event. Upon a sheet of paper he drew a circle, whose diameter was nearly equal to six inches. The circumference of this circle

he divided into 360° and its diameter into 30 equal parts, each of which was divided into four equal parts. He placed the object end of his telescope, previously adjusted to a focus, through an aperture in his window, towards the sun, and received its rays at right angles upon the paper. The sun's image exactly filled the circle. The room, of course, was darkened. It is quite evident, however, that he could not have kept the sun's image within the circle without the aid of some kind of equatorial or altazimuth mounting.

Hevelius, in his "Machinæ Cœlestis," a book published about 30 years after Horrox's death, gives a drawing of an altazimuth apparatus then in use. The telescope was passed through a turning sphere fixed in the window. The sheet of paper, which received the sun's image, was fixed at right angles to the axis of the telescope by means of a bar fastened to the tube of the instrument, and the paper disc could be revolved so that a diameter marked on it might be made vertical, the adjustment being perfected by the aid of a plumb line hung from a notched support which projected at right angles from the upper part of the disc. The whole rested upon a bench, which had two vertical pillars spirally grooved, by which the telescope and disc could be raised or lowered to any altitude. The movement in azimuth was followed by the block, into which the square bar and the support to the disc were inserted, being drawn along the bench, or the bench itself being pulled along the floor. Such a mounting, however, would be too complicated and too expensive for Horrox to use.

In the painting Horrox's arrangement is shown to consist of a wooden beam, upon which the telescope and the disc are supported, and the whole made to move as one piece. The beam is supposed to be held in position at the window by means of a hook and eye, or some such contrivance. This would give freedom of movement in following the sun in both altitude and azimuth. The beam could then be raised or lowered by resting it on planks placed upon the floor, and placed one above another, or upon a

bench with planks as the altitude required. For short periods the sun's altitude could be followed by the planks being drawn nearer to or further from the window. For following the sun in azimuth the bench and planks could be drawn along the floor, or the beam to which the telescope and disc were attached could be drawn gently along by the hand of the observer.

The painting shows Horrox drawing the beam towards him with his left hand while his right hand is free for keeping the graduated diameter of the disc vertical and in adjustment with the plumb line, for measuring distances with his compasses, or for taking notes.

In his description he speaks of his clock being "sufficiently correct." A table clock, such as was used in this days, is shown on the table. The poor curate was fortunate in having a watchmaker a near relative, one James Horrox, and doubtless he had procured or borrowed this instrument from him.

This remarkable observation, for which Horrox had made such calculations and preparations, unfortunately, happened on Sunday, a day on which he was fully engaged. The first contact he had reckoned would take place about 3 o'clock. As his afternoon service only finished at that time, as the sun set at 3.50, and as heavy clouds had been drifting across the sky the whole day, he hastened to his darkened room with great anxiety but eager with anticipation. He writes: "About 15 minutes past three in the afternoon, when I was again at liberty to continue my labors, the clouds, as if by Divine interposition, were entirely dispersed, and I was once more invited to the grateful task of repeating my observations, when, lo, I beheld a most gratifying spectacle, the realization of so many ardent desires—a new spot of unusual magnitude and of perfectly circular shape, which had already fully entered upon the sun's disc on the left, so that the limbs of the sun and Venus precisely coincided, forming an angle of contact. I immediately lost all doubt that this was the shadow of Venus, and applied myself to the careful observation of it."

During his search on this and the preceding day he had

watched a small sun-spot, "consisting as it were of three points," but this, he says, had nothing to do with Venus. This sun-spot is shown in the painting on the image of the sun.

On perceiving the new spot which he was fully convinced was the shadow of Venus, the young astronomer was overwhelmed with feelings of joy, rapture, and triumph. But such feelings must not interfere with the work he had then to do. If his previous labors were to result in benefiting science he must make good use of the thirty precious minutes during which the transit could be seen, and therefore, to use his own words in literal translation, he says, "I girded myself to the painstaking observation of that thing."

It is in this attitude of "painstaking observation," with all traces of emotion removed from his countenance, that the artist has depicted the youthful astronomer.

G. N. C.

GRAVITY.

By F. A. McDiarmid.

GRAVITATION is an attractive force which exists between any body and the earth in virtue of which they tend to move toward one another. It is a matter of common experience that all unsupported bodies near the surface of the earth fall to the ground, the direction of their motion being toward the centre of the earth. This phenomenon is due to the attractive force just defined as gravitation. The motion of the earth and other planets around the sun may be explained on the same basis. The mode of action of this force is given in the following generalization, first implicitly given by Newton, and known as Newton's *Law of Gravitation*. "Every particle of matter in the universe attracts every other particle with a force whose direction is that of the straight line joining their centres, and whose magnitude is directly proportional as the product of their masses, and inversely proportional as the square of their mutual distance; or if F be the force acting between two bodies of masses M_1 and M_2, at a distance D apart, then

$$F = kM_1M_2/D^2,$$

where k is a constant, known as the constant of gravitation.

Previous to Newton's investigations Kepler, by a truly prodigious amount of work, had deduced from the observations of Tycho Brahe the following kinematical laws of planetary motion: (1) The path of each planet is an ellipse, one focus of which is occupied by the sun; (2) The radius vector (i.e., the straight line which joins the centre of the sun to that of the planet) of each planet describes equal areas in equal times; (3) The square of the periodic times (i.e., the time during which a planet makes one complete revolution about the sun) of each planet is proportional to the cube of the major axis of the ellipse. From the second of

these deductions Newton showed that if the sun attracts the earth, or other planet, the direction of this attractive force must be in the line joining their centres; from the first and third he proved that its intensity must be inversely proportional to the square of their distance (so that, at double the distance the intensity of the attraction would be one-fourth, etc.). Lastly, the proof that the attraction is proportional to the product of the masses is found in the fact that the weight of any body is under all circumstances proportional to its mass. To test the truth of his deductions Newton studied the motion of the moon around the earth, and found that this satellite is retained in its orbit by an attraction which is exactly the same as that which causes a body near the earth's surface to fall with an acceleration of (about) 32.2 feet per second per second.

It must however be remembered that Kepler's laws are only approximately true, owing to the attraction of one planet on another interfering with what might be called the ideal state of things, and thus producing those small superposed motions of a planet which astronomers call perturbations. But it is just in this that the confirmatory proofs of the law of gravitation are found; for not only are all these perturbations explained by this means, but they have been discovered and measured by it.

The action of gravity is independent of the nature of matter, thus differing from magnetic attraction which is only found in a restricted class of bodies. At the same time the manner in which magnetic and also electric attraction depends upon distance is the same as gravitation. The force of gravitation is not affected by the presence of other matter; in other words, the weight of a body is the sum of the weights of its parts.

The intensity of gravity at the earth's surface is measured by the acceleration of a body falling freely under its influence, and is usually denoted by g. It varies slightly with the latitude, and the distance above sea level, and the density and nature of the topography surrounding the station of observation. Gravity increases from the equator to the pole. This is due to two causes; first,

owing to the ellipsoidal shape of the earth the force of gravitation is 1/590 greater at the pole than at the equator, and second, on account of the centrifugal force of the earth's axial rotation, bodies at the equator are 1/289 lighter than at the pole, where this axial equator has no effect; or the combined effects is to make a body 1/193 lighter at the equator than at the pole. A body will therefore decrease in weight as it is carried from the pole toward the equator. The number of swings a pendulum makes in a day or hour depends upon the attraction of the earth. The further we are from the centre of the earth the less will be this attractive force, and the fewer the swings of the simple pendulum in a given period of time. If a clock which keeps accurate time in latitude fifty degrees north be carried to the equator it will lose time.

The method employed to determine the force of gravity is that of the pendulum. If l is the length of the simple pendulum and t the period in seconds (the time between the passages of the lowest point of the pendulum by the middle point of the swing), and g the acceleration due to gravity, the time of a small oscillation in vacuo is expressed by the formula,

$$t = \pi \sqrt{\frac{l}{g}} \left(1 + \frac{a^2}{16} \right),$$

where a is the maximum inclination of the pendulum rod to the vertical and the unit of time is one second. With infinitesimal vibrations $t = \pi \sqrt{l/g}$. In order to obtain g, the value of the force of gravity, we must determine t, the time of one vibration, and l, the length of the pendulum. The time of one vibration, or the period of the pendulum, can be determined to a very fine degree of exactness, the units in the ten-millionth part of a second; but the length of the pendulum is very difficult to determine. So difficult is the problem of determining the absolute length of the pendulum that the method has been abandoned, and the relative method is used entirely. This method depends on comparing the periods of the same pendulum as determined at two stations, one of which is used as a base station. If the periods of the pendulum at the

two stations be t and t' seconds respectively, and g and g' the values of gravity at the two stations, then there is obtained the relation

$$t/t' = \sqrt{g'/g}; \text{ or } g' : g = t^2 : t'^2$$

or, the value of gravity at the two stations varies inversely as the squares of the periods of the pendulum, providing l, the length of the pendulum, remains constant. This method is now used by all the geodetic and geophysical surveys of the world. All determinations are based on some one point which, of course, has to be determined absolutely. The values of gravity at the different stations in the United States are all based on the value determined for the pier in the basement of the Coast and Geodetic Survey building at Washington. The value of gravity for this pier was obtained by comparisons of the periods of pendulums at Washington and Potsdam, Germany, by Mr. Putnam of the Coast and Geodetic Survey, the absolute value of gravity at Potsdam having been determined previously.

Canada is a new field for gravity research. In 1902 the Department of the Interior purchased a set of pendulums and the auxiliary apparatus, and Dr. Otto Klotz, Assistant Chief Astronomer, after standardizing the pendulums at Washington, observed at Ottawa, Toronto and Montreal, and in 1905 Professor Louis B. Stewart, of the University of Toronto, observed at North West River, Labrador. From 1905 till 1914 gravity observations were abandoned in Canada, but during the winter of 1913 and 1914 preparations were made for a systematic gravity survey of Canada. In order to have some repairs made to the instruments and also to restandardize the pendulums the writer was directed to proceed to Washington, where, on the pier in the basement of the Coast and Geodetic Survey building, the periods of the three pendulums of the Canadian set were determined. Observations were then made on the pier in the basement of the Dominion Observatory and thus Canada was connected to the gravity survey of the world. In order to check the observations and to strengthen the value of the result a second set of observations was made both

at Washington and Ottawa. The mean of the two determinations was accepted as the observed value of the force of gravity for Ottawa. The observed value for Washington is 980.112 dynes, and the value for Ottawa, as determined by the comparison of the pendulum periods at Washington and Ottawa, is 980.615 dynes. All stations in Canada are based on this value at the Dominion Observatory.

The Canadian pendulum outfit was patterned after the one constructed for the United States Coast and Geodetic Survey. In 1891, Professor Mendenhall, at that time superintendent of the Coast and Geodetic Survey, had constructed a half-seconds pendulum apparatus which has been in use ever since; and the Canadian pendulums are nearly exactly similar. The characteristics features are, three invariable non-reversible pendulums; an air tight receiver in which the atmospheric pressure is under control; a flash apparatus for noting coincidences between the oscillations of the pendulums and the two-seconds beat of the sidereal chronometer used in the observing; and a dummy or temperature thermometer.

Pendulums.—There are three pendulums in a set, and the period of each is determined separately and independently. The pendulums are made of an alloy of aluminum 10 per cent. and copper 90 per cent., a composition which experiment proved to have a very high resistance to corrosion; they are highly polished but not lacquered. Each weighs about 1,200 grams, and is about 248 millimetres in length from the centre of the bob to the agate plane. The stem and bob are designed to have as little resistance to the air as possible. The bob is solid, and is 9 centimetres in diameter and 4.5 centimetres thick at the centre. The stem of the pendulum is rectangular in section, 4 by 14 millimetres, with rounded edges, and is rigidly fastened to the head and the bob. The pendulums have an agate plane set in the head which rests on an agate knife edge on which they are swung. This knife edge is formed by carefully ground planes meeting at an angle of 130 degrees, thus insuring great permanency.

A small rectangular mirror is set in the side of the pendulum

head. This requires very careful adjustment, so that the image of the slit in the flash apparatus, described later, will be reflected into the same portion of the field of the observing telescope, when the latter is properly placed, and in line with the image of the fixed similar mirror on the plate carrying the knife edge.

The pendulums are carried to and from the box in which they are kept by a double-jointed handle which has leather lined hooks fitting under pivots on each side of the head. The pendulum should never come in contact with the hand; it is brushed before every observation with a very fine camel's hair brush. When placed in the receiver the pendulum is first suspended upon two pivots carried on the end of a lever, which pivots fit into corresponding sockets in the head of the pendulum. This lever is moved by a large screw which passes through the wall of the receiver so that the pendulum may be gently lowered and raised without injury to the knife edge, which could not so safely or readily be done directly by hand.

The temperature of the swinging pendulum is obtained by means of a dummy, similar to the others in material and dimensions, save it has no mirrors, and is so supported in the receiver that it cannot oscillate. It has mounted on its side a thermometer whose bulb is buried in the stem near the bob, and packed with the alloy filings, so as to obtain the temperature of the swinging pendulum.

Receiver.—The body of the receiver is a heavy brass casting, with walls seven millimetres thick, and of inside dimensions seventeen centimetres square at the top, twenty-one by twenty eight centimetres at the bottom, and thirty-eight centimetres high. The cover makes an air-tight joint when a little lard, tallow or vaseline is applied to the contact surfaces. A portion of the main casting forms a solid shelf, but having openings in it through which the pendulum, dummy and lever hang. This shelf carries on one side a plate on which the dummy pendulum is supported, and on the other the plate carrying the knife-edge on which the pendulum swings. This latter plate is supported on three points and firmly screwed to the shelf. To it is attached the adjustable fixed mirror

PLATE XIX.

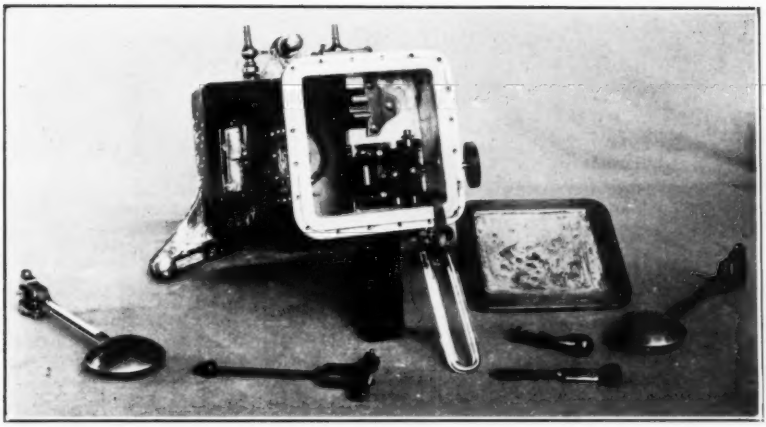

FIG. 1.

PENDULUM CASE WITH TOP REMOVED AND TURNED ON ITS SIDE TO SHOW INTERIOR. PENDULUMS AND OTHER PARTS IN THE FOREGROUND

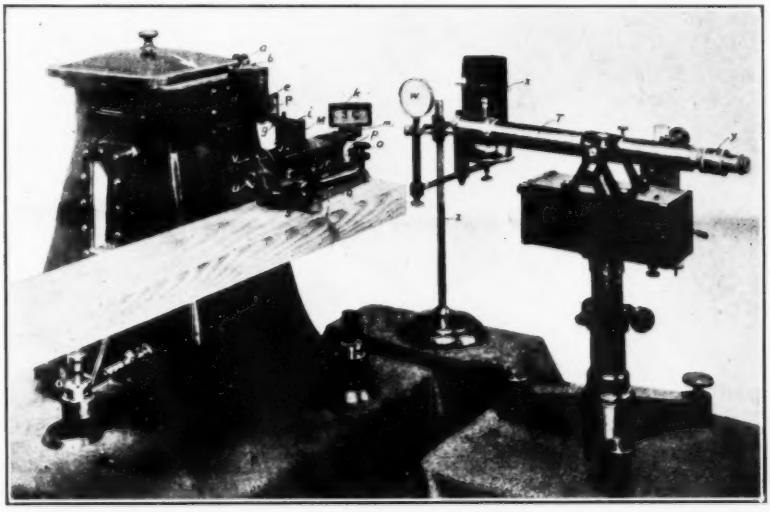

FIG. 2.

PENDULUM CASE AND OBSERVING APPARATUS, WITH INTERFEROMETER IN POSITION

which is so adjusted that the images of the slit, as seen in the observing telescope, reflected from this mirror, and from that on the pendulum when hanging freely at rest, will appear in the same horizontal line and will slightly overlap one another.

There is a scale below the pendulum and a small telescope mounted on the side of the receiver for reading the arc of oscillation. The receiver is supported on three heavy foot-screws resting on three heavy circular foot-plates which are cemented to the pier with plaster of Paris. The case is levelled in the plane of oscillation by the pendulum itself as shown by the reading of the tip of the pendulum on the scale beneath. In the transverse plane it is levelled by a small level mounted on a short pendulum which may be reversed on the knife edge. On the sides of the receiver are two levels to assist in levelling the case. Within the receiver is a short arm for setting the pendulums in motion. The point of this arm is covered with leather, and is worked from the outside. A mercury manometer is hung within the receiver, and by means of a portable air-pump the air pressure can be reduced to any amount required, generally to about fifty millimetres of mercury. Three windows are provided in the case for observing the mirrors, arc scale, dummy thermometer and manometer. The pendulums, receiver and air pump are shown in the accompanying illustrations (Figs. 1 and 2).

Flash apparatus.—The flash apparatus consists of a light metal box, mounted on a brass stand having both vertical and azimuthal movements and clamps, and carries with it an ordinary observing telescope, which may be focussed for objects within a few feet. (See Figure 2.) The object of the flash apparatus is to observe coincidences between the swinging pendulum and the chronometer. The box contains an electro-magnet, whose coils are connected with the chronometer circuit, and whose armature carries an arm which moves two shutters. By an ingenious device a flash of light is emitted from the box when the circuit is broken, but not when it is closed. A small oil lamp attached to one side of the box furnishes the light for the flash.

The details of the apparatus are too complica' l to be de-

scribed in full. It will be sufficient to say that the flash, as seen in the telescope, appears to travel by successive jumps up the field of view and then down, and by observing this motion the time of a single oscillation of the pendulum can be determined with great accuracy.

Use of apparatus.—The pendulum apparatus was always mounted in some place where the changes of temperature would be a minimum, and a cellar with a good dry concrete floor generally supplied this requirement. Three stones about five inches thick were used as the pier for the receiver. They were cemented to the concrete floor of the cellar with plaster of Paris and the receiver was placed on them. The change of temperature of these pendulum rooms rarely exceeded two centigrade degrees during the three days spent at a station. Before commencing observations care must always be taken to allow the pendulums and the receiver to reach the temperature of the observing room. If the temperature of the observing room is constant, thermometer readings at the beginning and the end of a swing will be sufficient, but if the temperature is fluctuating, then the thermometer must be read frequently. In order to keep the temperature constant it is well to close all windows and doors. Black cotton is used for darkening windows and cutting off extraneous light.

After the instrument has been mounted and adjusted, and the pressure inside the receiver reduced to nearly 50 millimetres, the pendulum is set swinging through an arc of about 5 millimetres amplitude; and the observer by means of a switch turns either of the observing chronometers on the flash apparatus and notes the coincidences through the telescope. In timing coincidences a hack chronometer, placed on the table near the observer, is used. A complete set of coincidences consists of two up and one down, or two down and one up. Readings are taken with both chronometers on the flash apparatus, the object of the two being to check the observations. The hack chronometer is always compared with the observing chronometers at the end of each set of coincidences. Readings of arc, thermometer and manometer are

made and recorded. After approximately eight hours the readings are again repeated. This completes a swing of the pendulum, which then is stopped and restarted and the readings again repeated. Each of the three pendulums is swung in three consecutive eight hour periods, and at the beginning of the swings the errors of the observing chronometers are determined either by star observations or by comparison with some standard sidereal clock whose rate is well determined. Also at the end of the third swing of each pendulum the errors of the observing chronometers are determined by either of the above methods. The advantage in determining the errors of the chronometers from comparisons with a standard clock rather than from star observations, is in the fact that the observer is not dependent on clear skies to obtain his clock error. It is believed that by swinging the pendulums continuously between time determinations, the effect of diurnal irregularities of rate are entirely eliminated, as it will not be by any other method, and this has been strikingly shown in the Canadian observations of the summers of 1914 and 1915. The average errors in the periods of the pendulums at the different stations is less than 0ˢ.0000001, and the maximum error is about 0ˢ.0000004. The chronometers were rated by comparison with the standard sidereal clock of the Dominion Observatory. Signals were sent over the telegraph line and recorded at the observing station on a chronograph sheet, on which were also the records of the two observing chronometers.

Below follows a set of observations:—

Station: Cochrane. Date: 31st July, 1914.

PENDULUM 1, SWING 1.

Bond No. 519.				"19"	Dent No. 52866.				"26"
D 13h.	48m.	13s.		3m. 17s.	D 13h.	50m.	07s.		3m. 17s.
U 13	51	30		3 13	U 13	53	24		3 16
D 13	54	43	Mean	3 15	D 13	56	40	Mean	3 16.5

Arc.	Pressure.	Temperature.
mm.	mm.	
2.6	23.0	
3.0	25.0	17°.15
5.6	48.0	

			"38"				"45"	
D	21h.	11m. 06s.	3m. 14s		D	21h.	11m. 55s.	3m. 16s.
U	21	14 20	3 15		U	21	15 11	3 12
D	21	17 35	Mean	3 14.5	D	21	18 23	Mean 3 14

Arc.	Pressure.	Temperature.
mm.	mm.	
1.2	29.0	
0.7	27.0	17°.25
1.9	56.0	

Note.—The figures in quotation marks, as "19" above, are the seconds of the hack chronometer at the even minutes of the observing chronometers.

Reduction of observations.—From the coincidence interval (i.e., the mean period between an "up" coincidence and a "down" coincidence), is derived the periodic time of the pendulum uncorrected for arc, pressure, temperature, rate and flexure. The reduction must be made to infinitely small arc, to standard pressure and temperature; a correction for rate of observing chronometers and for the flexure of the pendulum case must be applied. The standard pressure is 60 millimetres of mercury, and the standard temperature is 15° Centigrade. These standards were closely realized in each case and the consequent corrections were small.

The arc correction is given by the following formula,

$$A = \frac{PM.\ \sin(\phi + \phi')\ \sin(\phi - \phi')}{32\ (\log \sin \phi - \log \sin \phi')}$$

where P is the period of the pendulum in seconds, ϕ is the initial semi-arc, ϕ' is the final semi-arc, and A is the amount to be subtracted from the period to reduce to infinitely small arc.

The temperature correction is $(15° - T)\ (0^s.00000419)$, where T is the observed temperature in degrees Centigrade.

The pressure correction takes the form of

$$C = k\ [60 - Pr./(1 + 0.00367T)],$$

where C is the correction in seconds (to be subtracted if observed density is above the standard and added if below the standard), k is the pressure coefficient, or variation in period for change of 1 millimetre in pressure (at 0° Centigrade), $Pr.$ is the observed pressure in millimetres of mercury, and T is the mean temperature in degrees Centigrade. The value of k for the Canadian instruments is $0^s.000000101$.

The rate correction is given by the formula,

$$D = 0^s.00001157RP,$$

where D is the correction to period (to be subtracted if the chronometer is gaining and added if losing), R is the daily rate of the chronometer in seconds, and P is the period of the pendulum in seconds.

The horizontal component of the force acting on the knife edge through the swinging pendulum causes the support to move in unison with the pendulum, and therefore affects the period of the oscillation. This movement is called the flexure of the pendulum support. The movement or displacement is an exceedingly small quantity, and Mr. W. H. Burger of the United States Coast and Geodetic Survey first used the interferometer to measure this movement.

The principle of the interferometer is shown in the accompanying diagram (Fig. 3). The beam from the source of light (*) with its rays made parallel by a lens L, strikes the rear or second surface of the plate S, and separates, part of it being reflected to the plane mirror P, returns exactly on its own path through S, and then through C to T where it is examined by a telescope T. The other part goes through the plate S, passes through the plate C, and is reflected by the mirror M, returns on its own path through C to the plate S, where it is reflected so as to unite with the first ray as to produce interference. The result is a series of bands in the form of a grating, as shown in Fig. 4, the dark band being produced when the two wave trains

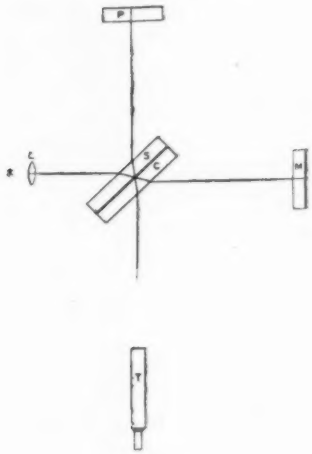

FIG. 3.

DIAGRAM TO EXPLAIN THE ACTION OF THE INTERFEROMETER

differ by one-half a wave-length of light, and the light bands when they are in the same phase.

One mirror is attached to the pendulum receiver and the remainder of the interferometer is mounted on a support entirely independent of the pendulum receiver. Any movement of the

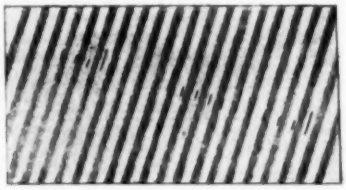

FIG. 4.

FRINGES AND SCALE

pendulum receiver will produce a shift or displacement of the fringes in the interferometer. Since the pendulum makes one

complete swing in one-half a second, the shift of fringes will occur as a half-second shift across the field. This movement is a measure of the amount of flexure in the pendulum case caused by the oscillation of the pendulum.

The method employed to determine the flexure at the pendulum stations was to observe the width of a fringe in terms of a division of the scale in the telescope, and then observe the amount of the shift or displacement of the fringe band in terms of the scale divisions. The second quantity divided by the first will give the shift of the fringes in terms of their width. The light used is monochromatic, easily produced by the use of sodium chloride and an alcohol flame.

If the fringes shift, or are displaced one fringe-width due to the motion of the pendulum, it is easily seen that the pendulum case has moved through a distance equal to one-half the wave-length of the light used, for a change of distance between the thinly silvered plate and the mirror on the pendulum case causes a change in the total path of the ray to and from that mirror by double that amount, so that if the length of the ray of light used is known we have a means of computing the movement of the case. The wave-length of sodium light is practically 0.58 microns, and therefore a shift or displacement of the fringe by an amount equal to one fringe-width means a displacement of the pendulum case of 0.29 microns. The correction to be applied to the period of the pendulum, when the receiver is mounted as in the Canadian work, is about 0s.0000011, to be subtracted.

Below is an example of the computation of the observations made at Cochrane on 21st July 1914:

		Bond		Dent
		s		s
Period uncorrected		0·5012838		0·5012869
Correction for arc	−	12	−	12
" " temperature	−	91	−	91
" " pressure	+	11	+	11
" " rate	−	146	−	177
" " flexure	−	11	−	11
Corrected period		0·5012589		0·5012589

Deduction of the absolute gravity.—The ratio of the gravity at two places is given by the relation $P^2 : P_x^2 = g_x : g$, or $g = (P_x/P)^2 g_x$, where P_x and g_x are period and gravity at the base station and P is the period at the field station. The observed value for Ottawa is 980.615 dynes, and the gravity at any station can readily be deduced when the period of the pendulum is known for Ottawa and for the field station.

During the summers of 1914 and 1915 pendulum observations were made at 42 stations in Canada. These stations are scattered from Sydney in Nova Scotia to Vancouver in British Columbia; they cover about nine degrees of latitude. It is the intention in the near future to make observations at many more stations in our great north-west, and also in other parts of Canada. The question may be asked: "What is the practical value of these observations?" That question probably can best be answered by quoting from a paper read by Mr. C. S. Peirce before a conference on gravity determinations held at Washington in May, 1882.

"(1) The first scientific object of a geodetic survey is the determination of the earth's figure. It is probable that pendulum experiments afford the best method of determining the oblateness of the spheroid of the earth, for the calculated probable error in the determination of the quantity in question from pendulum observations does not exceed that of the best determination from triangulation and latitude observations. Besides, the measurement of astronomic arcs upon the surface of the earth covers only limited districts, and the oblateness deduced from them is necessarily affected. On the other hand pendulum determinations are subject to no great errors which least squares cannot ascertain; they may be widely scattered over the earth, they may be numerous, they are combined to obtain the ellipticity by a simple arithmetical process; and the calculated probable error deduced from them is worthy of unusual confidence. It is very significant that while the value derived from pendulum work has remained very constant, that derived from measurements of arc have been continually changing as more data have been secured, and the change

has always been in the direction to accord with the pendulum method. Also, the expense of the pendulum method is small compared with the geodetic method.

(2) Investigation has shown the importance of pendulum experiments to metrology.

(3) Geologists affirm that from the values of gravity at different points useful inference can be drawn in regard to the geological formation of the underlying strata.

(4) Gravity is extensively employed as a unit in the measurement of forces. Thus, the pressure of the atmosphere is, in the barometer, balanced against the weight of a measured column of mercury; the mechanical equivalent of heat is measured in foot-pounds, etc. All such measurements refer to a standard which is different in different localities, and it is therefore very important to determine the amounts of these differences as the exactitude of measurement is improved.

(5) It is hoped that as the knowledge of the constitution of the earth's crust becomes, by the aid of pendulum experiments, more perfected we shall be able to establish methods by which we can with confidence infer from the vertical attraction of mountains, etc., what their horizontal attraction, and the resulting direction of the plumb-line must be.

(6) Although in laying out the plan of a geodetic survey the relative utility of the knowledge of different quantities ought to be taken into account, and such account must be favorable to pendulum work, yet it is true that nothing appertaining to such a survey ought to be neglected. The knowledge of the force of gravity is not a mere matter of utility alone, it is also one of the fundamental kinds of quantity which it is the duty of a geodetic or geophysical survey to measure. Astronomical longitudes and latitudes are determinations of the direction of gravity; pendulum experiments determine its amount. The force of gravity is related in the same way to longitude and latitude as the intensity of the magnetic force is related to the magnetic declination

and inclination, and, as a magnetic survey would be held to be imperfect in which measurements of intensity were omitted, to the same extent must a geodetic survey be held to be imperfect in which the determinations of gravity have been omitted."

The value of gravity at a station depends upon the latitude of the station, upon the elevation above sea level, and upon the nature and density of the topography surrounding the station. Perhaps in a later paper these problems may be discussed, but in this article it is only the intention to outline briefly the methods of observing with the simple pendulum, and the value of the deduced result.

DOMINION OBSERVATORY,
OTTAWA, CANADA.
November, 1916.

THE QUESTION OF DIFFUSED LIGHT IN MOUNT WILSON SOLAR OBSERVATIONS.

By C. E. St. John and W. S. Adams.

In the September number of The Journal Mr. DeLury, (Journal Royal Astronomical Society of Canada, Vol. X., 353, 1916) states his conclusion that the observations of solar rotation made at Mount Wilson are affected by a strong overlapping sky or haze spectrum. To account for the differences between the rotational velocities obtained for the strong magnesium lines of the *b* group and for the lines of unit intensity he predicates in the Mount Wilson observations a superposed spectrum of about 9 per cent. A sky or haze spectrum of the intensity indicated would, of course, seriously handicap a solar observatory, making it difficult, for example, to obtain spectroheliograms showing the finest detail and sun-spot spectra of satisfactory quality.

We would like to present the following observations and considerations which bear directly upon the Mount Wilson sky conditions:

A. In this connection reference may be made to Abbot's investigation of the sky at Washington by means of drift curves taken along the diameter of the solar disk. He says (*Annals of the Astrophysical Observatory of the Smithsonian Institution*, vol. 2, p. 223): "From the examination of numerous records it appears that the total deflection produced by the sky radiation and all other causes combined, at a point 1.5 per cent. of the radius outside the computed width of the disk, is certainly less than 1 per cent. of the deflection at the centre of the disk, . . . but the greater portion of the deflection observed outside the computed boundary is attributable to diffraction, 'boiling' tremor and other defects of the image rather than to sky radiation." Such drift observations are now a matter of daily routine at the Smithsonian station

on Mount Wilson. These have not yet been reduced but an inspection of the curves shows that, with a sensitiveness of the bolometric apparatus sufficient to yield curves with 125mm. ordinates for the centre of the sun, no measurable deflection is discernible at points off the edge of the disk and beyond the effects of bad seeing. These curves may be considered to represent the average conditions on Mount Wilson rather than the conditions on selected days, such as are taken for solar rotation observations.

B. Recently the following test of conditions was made: the slit of the spectograph was placed normal to the limb and exposures were made just within and outside the limb, the two points being 1mm. apart. For equality of blackness of the two spectra, it was necessary to make the exposure for the point just off the disk 100 times as long as for the edge of the disk itself. A day was chosen when light clouds were around the horizon and the sky itself was termed "whitish." The region included the H line of calcium. For this spectral region scattering should be relatively large. The light scattered by sky, haze and instrument did not exceed one per cent. of the light from the edge of the disk and probably not one-eight of one per cent. of the light from the centre of the disk.

C. In order to determine whether this small amount of scattered light was sufficient to affect the solar rotation observations a direct test was also made. These observations are made with the 150-foot telescope, giving at present an image 420mm. in diameter, and observations on the east and west limbs are secured simultaneously, the light being taken from the opposite ends of the solar diameter by totally reflecting prisms. In the test one of these was set as usual 3mm. inside the west limb, and the other 1mm. outside the east limb. The normal exposure of 4 minutes was given, followed by the normal development. Not the slightest indication appeared of any spectrum outside the limb, although there was sufficient diffused light in the spectograph pit to carry the photographic plate over the threshoid value. To obtain equal

blackness it is estimated that an exposure of at least seven hours would have been required. The sky conditions at the time were as unfavorable as they ever are when solar rotation observations are undertaken. Moreover, the mirrors were old and unusually tarnished; in fact, the resilvering had been delayed and the usual burnishing omitted that the conditions might be as favorable as possible for scattered light.

The above results indicate with a high degree of probability that scattered radiation, whether from sky, haze or instruments, is, under the usual working conditions at Mount Wilson, a negligible quantity and therefore is not a probable source of error in the observations upon solar rotation.

MEETINGS OF THE SOCIETY

AT TORONTO.

October 3, 1916.—A regular meeting of the Royal Astronomical Society of Canada was held in the Society's rooms at 198 College St., at 8 p.m., the President, Dr. Albert D. Watson, in the chair.

The secretary reported that in connection with the request of Col. Gordon the officers of the Society had loaned the Society's 2-inch telescope.

It was moved by Mr. A. F. Hunter, and seconded by Dr. W. M. Wunder, that the action taken by the officers of the Society in loaning the 2-inch telescope to the military authorities be approved. Carried.

Under Reports of Observations, a number of the members reported having seen a great many auroræ during the summer, and a particularly pronounced one on the 26th of August.

Professor Chant was then called to speak on "Some Aspects of American Astronomy." The speaker stated that during the summer he had attended the meeting of the American Astronomical Society at Swarthmore and conversation with the scientific men in attendance indicated a very sympathetic feeling for the Allies and their cause. He then referred briefly to the various papers presented to the Society and stated that an account of the meeting would appear in the next issue of the JOURNAL, as reported by Mr. W. E. Harper of the Dominion Observatory.

Some recent photographs of nebulæ, zodiacal light, and the gegenschein were exhibited on the screen.

October 17.—The regular meeting was held in the Society's rooms, 198 College Street, at 8 p.m., Dr. Albert D. Watson, President, in the chair.

The following were elected members of the Society:

John Satterly, M.A., D.Sc., Toronto.

A. R. Hassard, B.C.L., Toronto.

Thos. Armstrong, M.D., Toronto.

The lecture of the evening was given by F. A. McDiarmid, B.A., President of the Ottawa Centre, the subject being "Gravity." Mr. McDiarmid briefly outlined the history of the subject, telling how the observations of Tycho Brahe were necessary to Kepler and Newton in determining their fundamental equations, and then explained the different methods used in determining the Gravity at the earth's surface with a description of the instruments used by himself in the Gravity survey of Canada and their standardization. He showed how the topographic and isostatic compensations were applied and the reasons for doing so. The results of the work already done in Canada were exhibited on a slide.

October 30.—The regular meeting of the Royal Astronomical Society of Canada was held in the Society's rooms at 198 College Street, at 8 p.m. Professor C. A. Chant in the chair.

The following were elected members of the Society:—

John B. Fraser, M.D., Toronto.

Mrs. F. H. Deacon, Toronto.

With the approval of the meeting, the chairman appointed the President and Corresponding Secretary a committee to prepare and send to Sir Frederic Stupart an expression of our deep sympathy in the loss of his eldest son on the field of battle.

The lecture of the evening was by Professor G. R. Anderson, on "Photography in Colors." The various methods employed in obtaining photographs in color were carefully explained and profusely illustrated. Slides were shown of different natural objects procured by the various processes, and results obtained were very excellent.

W. E. W. Jackson, *Rec.-Sec.*

NOTES FROM THE DOMINION OBSERVATORY

In connection with the longitude work carried on each year by the Observatory, the need has long been felt for a somewhat more extended list of accurate right ascensions than that contained in any of the ephemerides. Of the three fundamental catalogues, that of Newcomb is most suitable as regards number of stars; the positions of many of these, however, even including some of those which find a place in the ephemerides, leave much to be desired. For determinations of longitude in northern latitudes, it is also desirable (unless a broken-tube type of telescope is employed) to have available for use a larger number of stars north of 70° declination than is contained in any of the fundamental catalogues.

With these facts in view, a series of observations of right ascension was carried out in 1910 at the Observatory; the observing list comprised most of the northern stars in Newcomb's Fundamental Catalogue, with the addition of a number of other stars north of 70° declination. This work was not carried to as complete a state as might have been wished, for the reason that a more extended list of latitude stars was also much required, and work was begun on this. The data available were, however, found to be sufficient for a considerable improvement on existing catalogues, especially for the summer-culminating stars most required for longitude work, and it was decided to work up a list of right ascensions, combining these observations with the already existing material.

In forming this catalogue, the system of Boss was adopted as fundamental, and, after a careful comparison, systematic corrections to the Ottawa observations, depending on the declination, were adopted and applied; no systematic differences depending on right ascension, which could be certainly classed as real, were found, and none were applied; none of the adopted corrections amounted to more than 0^s.02 sec. ; no difference depending on magnitude was found. For stars north of 70°, the Greenwich Ten Year Catalogue for 1900 was also employed; a correction to the published positions, to reduce them to the mean of observations above and below pole, was applied, as was also a magnitude-correction (the same as applied by Boss to the Greenwich catalogue for 1890); the positions were then compared with those of Boss, and a correction depending on the declination adopted.

A solution was then made for each star, to determine the correction applicable to the right ascension and proper motion as given in Boss's Preliminary General Catalogue.

The catalogue contains in all 519 stars, included between the limits of declination +10° and +85°; the epoch is 1910; it contains the corrected right ascensions and proper motions, together with annual variations, secular variations and values of the "third term"; also the mean epoch of observation, the probable error at the epoch, and probable error at 1925; there are also given for all stars contained in these, the corrections in right ascension and proper motion to the catalogues of Boss, Auwers and Newcomb. Declinations are entered to the nearest second only, and are taken from Boss's catalogue.

R. M. Stewart.

NOTES FROM THE METEOROLOGICAL SERVICE

Summary Report of the Weather in Canada

October, 1916

Temperature. — The mean temperature of the month was considerably below average from Manitoba westward to British Columbia, the negative departures being as much as 5° and 6° in Western Manitoba and Southern Saskatchewan. From Lake Superior eastward the average was very generally slightly exceeded, but in some districts near Lake Huron and in Nipissing, the mean was slightly below average.

Precipitation.—The total precipitation was less than average in British Columbia, Nova Scotia and Prince Edward Island, and above average in the other Provinces, excepting in districts immediately to the north of the western half of Lake Superior. The largest positive departures were in Ontario, near Lake Huron and the Georgian Bay, and in parts of Quebec, and the largest deficiency was in the lower mainland of British Columbia. Snow formed a large percentage of the total in many parts of the Prairie Provinces, the fall at Qu'Appelle aggregating 25 inches. The snow, however, had disappeared in practically all sections by the 31st.

Temperature for October, 1916

Station	October		Station	October	
	Highest	Lowest		Highest	Lowest
Yukon			Kenora	62	17
Dawson	46	4	Kinmount	77	21
British Columbia			Kingston	75	28
Atlin	58	15	Kitchener	83	24
Agassiz	73	29	London	84	27
Barkerville			Lucknow	79	25
Kamloops	72	24	Markdale	92	26
New Westminster	68	31	North Gower	78	20
Prince Rupert	62	34	Oshawa		
Vancouver	61	31	Ottawa	78	26
Victoria	67	38	Paris	83	24
Western Provinces			Parry Sound	76	28
Battleford	71	21	Peterboro'	86	21
Calgary	74	18	Port Arthur	69	26
Edmonton	72	20	Port Burwell		
Medicine Hat	78	21	Port Dover	76	28
Minnedosa	64	4	Port Stanley	69	27
Moose Jaw	75	14	Queensborough	81	18
Oakbank	64	12	Ronville	78	23
Portage la Prairie	71	11	Southampton	80	30
Prince Albert	64	10	Sundridge		
Qu'Appelle	72	12	Stonecliffe	84	28
Regina	74	4	Stony Creek	86	26
Saskatoon	66	10	Toronto	85	30
Souris	65	4	Uxbridge	82	27
Swift Current	74	12	Wallaceburg	83	28
Winnipeg	65	14	Welland	80	27
Ontario			White River	72	11
Agincourt	86	25	*Quebec*		
Aurora	80	26	Brome	78	19
Bancroft	77	18	Father Point	62	28
Barrie	86	29	Montreal	74	28
Beatrice	73	23	Quebec	71	25
Bloomfield	77	24	Sherbrooke	77	24
Brantford			*Maritime Provinces*		
Chapleau	76	19	Charlottetown	72	30
Chatham	86	30	Chatham	82	26
Clinton	79	28	Dalhousie	78	26
Collingwood	89	24	Fredericton	81	20
Cottam	85	19	Halifax	78	26
Georgetown	81	26	Moncton	79	20
Goderich			St. John	75	30
Gravenhurst			Sussex	75	19
Grimsby	86	29	Sydney	78	30
Guelph	80	25	Yarmouth	67	27
Haliburton	78	21			
Huntsville	78	23			

Earthquake Records by the Milne Seismograph

TORONTO

Sir Frederic Stupart, Director.

P.T. = Preliminary Tremors, L.W. = Large Waves. A.C. = Air Currents.
Time is Greenwich Civil Mean Time, 0 or 24 h = midnight.

No.	Date 1916	P. T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm.	
1640	Oct. 1			2 10·5		2 14·7	0·1	A.C. going on.
1641	" 3	1 36·8	1 45·1	1 52·5) 1 56·7)	2 3·3	A.C.	1·5	Repeat 2h 42m·3 6,785 km.
1642	" 3			5 01·3		A.C.		ling seismic.
1643	" 3			14 01·8		A.C.	0·2	Doubtful as to be-
1644	" 6			16 28·8		A.C.	0·1	Doubtful as to be-
1645	" 11			10 48·4) 11 04·9)		A.C.	0·1	ling seismic- Doubtful as to be-
1646	" 11			18 24·6) 18 28·0)	19 05·8	A.C.	0·3	ling seismic.
1647	" 13			1 14·3		A.C.		
1648	" 20			17 33·3?	17 34·8?	A.C.	0·2	
1649	" 21			20 42·6		20 45·1	0·05	Minute thicken'g
1650	" 21			22 25·1?) 22 40·1)	22 54·4	A.C.	0·3	
1651	" 22			8 29·0		8 36·5	0·1	Gradual thicken- ling.
1652	" 31	15 52·3	16 01·3	16 11·0) 16 18·6)	16 24·4	18 54·2	2·8	7,600 km. Phases well defined. P. and S. strongly marked at begin- ning.

Period of boom 18 seconds. Pillar inclination 0″·50.

Note.—Error in numbering corrected.

VICTORIA, B. C.

F. N. DENISON, SUPERINTENDENT.

No.	Date 1916	P.T. Comm.	S. Comm.	L.W. Comm.	Max.	End	Max. Amp.	Remarks
		h m	h m	h m	h m	h m	mm	
1650	Oct. 1		2 54·5?		2 56·5	2 58·0	0·05	
1651	" 3	1 38·5	1 49·0	1 58·5	2 13·5	4 22·8	2·5	9400 km.
1652	" 3			4 56·5		4 59·5	0·3	May be reflected waves.
1653	" 3	13 40·7		13 43·8	13 44·9	13 48·4	0·2	
1654	" 6		16 25·0?		16 28·0	16 30·4	0·2	
1655	" 11		11 31·6		11 32·6	11 38·0	0·1	
1656	" 11			18 27·6	18 28·1	18 34·0	0·5	Probably two quakes.
1657	" 11			18 46·9	18 56·4	19 26·1	0·2	
1658	" 13	1 13·1?		1 14·8	1 16·3	1 18·3	0·2	
1659	" 19		11 57·3?		11 58·3	12 00·8	0·05	
1660	" 20	17 27·3	17 31·3	17 37·8	17 46·8	18 36·3	0·75	2440 km.
1661	" 21	22 35·6?	22 37·6?	22 40·6?	22 44·0	23 08·8	0·4	P. S. and L. uncertain
1662	" 22	8 03·0?			8 06·5	8 11·0	0·1	
1663	" 23	10 58·1?	11 00·5?	11 05·0	11 07·5	11 10·5	0·1	
1664	" 25	8 56·6?		8 58·6?	9 00·1	9 05·1	0·1	
1665	" 26			19 05·2?				
1666	" 30	11 33·6?			11 35·1	11 39·6	0·1	
1667	" 31	15 37·7?	15 40·1	15 46·6	15 52·5	17 40·1?	1·0	Reflect 18h 38m 7.

Boom period 18 seconds. Pillar inclination 0″·54

J. V.

MAGNETIC OBSERVATIONS

September, 1916

The magnetic curves obtained at Agincourt during the month of September, 1916, indicate almost continuous disturbance in the magnetic forces. The larger disturbances occurred on September 3, 4, 5, 12, 17, 26, 27 and 30. In most cases there were no very large departures from normal but considerable activity was evident.

The first storm began about noon of the 2nd and continued until noon of the 5th. The D and Z curves exhibit the most pronounced movements between 16^h of the 4th and 9^h of the 5th. The D curve appears somewhat like the teeth of a saw up to midnight and the mean declination is less west than normal. After midnight two moderately large positive departures are recorded. The Z curve is above normal up to 19^h of the 4th, when a succession of negative swings, at intervals of about an hour until 3^h of the 5th, each carry the force to a lower value after which it returns gradually to normal about 9^h of the 5th. The movements in H are less pronounced but fairly active throughout the whole period.

The storms of the 12th and 17th are only moderate, but still large enough to obliterate the usual diurnal curve.

On the 26th the West Declination decreased rapidly at $17^h\ 39^m$ and remained below normal until $21^h\ 10^m$ when a fairly large increase took place, after which the storm gradually diminished in energy. The Z increased slightly to 17^h followed by two fairly large decreases having their minimums at 22^h of the 26th and 4^h of the 27th. H was only moderately disturbed.

The storm on the 30th is again most noticeable in the D. Between 6^h and 8^h the D curve has a large plus West swing and between 18^h and 22^h some very rapid vibrations both above and

below the normal. Some fairly rapid vibrations are also recorded between 18^h and 22^h in the Z.

At Meanook the days of larger disturbance are the same as at Agincourt but the characteristics of the disturbances are dissimilar. The D at Meanook between the 2nd and 5th shows considerable activity but the amplitude is small. On the 26th variations at $17^h\,40^m$ (75th M.T.) are small, and between 20^h and 21^h fairly large, but between 2^h and 5^h of the 27th they are much larger and more rapid. On the 30th a large easterly swing is recorded between 4^h and 10^h followed by pulsations all day and a small increase between 21^h and 22^h.

A small group of sunspots south of the equator passed around the limb on the 10th. A large group appeared on the limb to the north of the equator on the 8th and the last of it disappeared around the west limb on the 22nd, and great changes were noted in its appearance during this time. A small penumbral spot observed on the 19th had disappeared on the 23rd.

Very few auroræ were noted during the month. At several places in the western provinces an aurora was recorded on the 27th.

AGINCOURT MAGNETIC OBSERVATIONS

Lat. 43° 47′ N.; Long. 79° 16′ W.

September, 1916		D. West	H	Z	I
	Mean of Month	° ′ 6 33·9	0·15974	0·58523	° ′ 74 44·0
	Maximum	7 08·7	0·16071	0·58647	
	Date of Maximum	5	4	4	
	Minimum	5 54·6	0·15862	0·58381	
	Date of Minimum	30	3	3	
	Monthly Range	1 14·1	0·00209	0·00266	
Mean Daily Amplitude	From hourly readings	0 12·2	0·00050	0·00030	
	From means of extremes	0 26·6	0·00089	0·00071	

H and Z are expressed in C.G.S. units.

MEANOOK MAGNETIC OBSERVATIONS

Lat. 54° 37′ N.; Long. 113° 21′ W.

September, 1916		D. East	I
		° ′	° ′
	Mean of Month	27 49·3	77 56·0
	Maximum	29 20·3	
	Date	3	
	Minimum	26 56·2	
	Date	27	
	Monthly Range	2 24·1	
Mean Daily Amplitude	From hourly readings	0 10·8	
	From means of extremes	0 44·8	

All results are reduced to International Magnetic Standard.

W. E. W. J.

ASTRONOMICAL NOTES

EGYPTIAN ASTRONOMY AND THE ZODIAC.—In a recent number of the *Bulletin de l'Institut Français d'Archéologie Orientale* (cxii.) of Cairo, M. Georges Daressy, one of the foremost among French Egyptologists, treats of the knowledge of the constellations in ancient Egypt. His article is entitled "L'Egypte Céleste," by which words he means the duplication of the geography of the Nile valley into the sky,' for the priests mentally projected another Egypt into the northern heavens. By a kind of symbolic celestial geography the daily solar journey was considered as a descent or voyage of the sun upon a river, the duplicate of the Nile, but situate in the firmament.

This conception having been evolved, to render the allegory geographically complete, it became necessary to have a series of "nomes," or counties, alongside the celestial river upon the banks, the district deities of which should correspond with those of similar sites through which the terrestrial Nile wended its way. For this purpose they selected the path of the ecliptic and identified that with the Nile's course. Precisely as each Nilotic "nome" possessed its own deity with his, or her, special totem symbol, so the Egyptian "wise men" provided parallel deity figures for their celestial river upon which the sun voyaged. With this object they adopted the zodiacal signs—the decans, the planets, and various constellations—because they required stellar associations, not only for the forty-two "nomes" but also for more than one temple, or important shrine, and its attendant city in many of the "nomes."

The event which induces M. Daressy to publish the fruits of his erudition upon this subject is the publication by him of a bronze zodiac with a series of two rows of twelve figures, the outer zone being the familiar zodiacal signs, and the inner, twelve animal symbols, attributable, Egyptologists think, to the twelve forms or phases assigned to the sun during his twelve hours' journey. These, in the earthly Egyptian gazetter, are assigned to twelve of the twenty districts of Lower Egypt. This newly found double zodiac is very valuable for the explanat on it affords of the symbols of the constellations upon the Denderah zodiac, because all these figures are intermingled in the large central circular disc, mixed up with deity figures representing the planets and certain prominent high-magnitude stars and the decans.

It should be stated that the zodiacs designed, and hitherto found, in Egypt are not of great antiquity. The arrangement of their symbols and of figurative objects for some constellations has certainly been produced under Greek influence. They appear to emanate from the Egyptian priests uniting their old stellar figure mythologies to the astronomical astrology of the Alexandrian school. Both parties, however, must at the date of the composition of these zodiacs have been acquainted with the Chaldean science of the heavens, derivations from which appear in the Old Testament and early Greek classics and art.

The deity symbols upon the Babylonian boundary stones are almost always astral and frequently zodiacal. Since the large increase in number of these monuments found at Susa, we have a much more complete series of the symbols.

Thus upon the stele of Melishipak we have the figure of an archer with the upper part human and the lower part that of a double-headed horse and two tails; those of a horse and a scorpion; also wings. This representation agrees almost completely with the Sagittarius of the Denderah zodiac, and with this Sagittarius the scorpion is associated in both cases.

This assimilation of Mesopotamian astronomy is identical with the adoption by the Egyptians of several Babylonian legends

of the gods into Egyptian mythology. These exploits were foisted upon the deeds of Egyptian deities. For example, the Izdubar (Hercules) legends were in some cases introduced into the conflicts of Horus.

The parallels between terrestrial Egyptian geography and the places of the stars must, however, have been very old in Egypt, though not anterior to the era of Menes. M. Daressy ingeniously explains the principles upon which these were arranged, and henceforth Egyptologists will trace in the primitive texts allusions to them and decide approximately when they were invented. The favorite constellations other than the zodiac were the circumpolar stars, because they never set and so were symbolic of eternity.

In addition to the famous zodiac from Denderah, now in the Louvre, we have, among others, the new one at Cairo, the planisphere and tableaux carved on the hypostyle hall at Denderah, copies of others once at Esneh and Erment, and the coffin of Hern-netch-tep in the British Museum.—Joseph Offord, in *Nature*, September 7th, 1916.

A Brilliant Meteor.—A meteor of great size and beauty was seen here on the evening of October 20th. It was first observed at 10.36, and was moving slowly from the neighborhood of Markab, in Pegasus, in an easterly direction. In its course it travelled across the constellation Pisces, passed somewhat below Mira, in the constellation Cetus, and finally disappeared behind some rising ground which concealed from view part of the constellation Eridanus, into which it had just entered. As the object crossed the sky some 18 degrees below Jupiter, a favorable opportunity was afforded of comparing the relative brilliancy of the two objects, and when the meteor was at its brightest I estimated the light coming from it to be equal to from four to six times that of the planet. For a second or two, when the meteor was at its best, the landscape was very visibly illuminated, and strong shadows were cast. The light given out by the meteor was intensely white, and during its progress across

the sky fragments of luminous matter were being constantly thrown off, but these quickly died out. The meteor had a tail of considerable length, which, illuminated by the body, presented a beautiful, soft, vapory appearance.—Wm. S. Cumming, F.R.A.S., in *English Mechanic and World of Science*, No. 2693.

Harvard College Observatory, *Bulletin* 618.—A comet was discovered by the Rev. Joel H. Metcalf on November 21, having the following approximate photographic positions:—

G.M.T. 1916	R.A. h m s	Decl. ° ′	Observer	Place
Nov. 21·5673	3 38 0·5	+ 18 32·8	Metcalf	Winchester
22·5396	3 37 49·3	17 58·4	Metcalf	Winchester

The comet is very faint, but eight photographic images have been obtained. This is the fourth comet discovered by Mr. Metcalf.—Edward C. Pickering, Director.

Lowell Collection Astronomical Photographs.—A total of 1348 people visited the Roger Williams Park Museum yesterday afternoon to see the photographs of astronomical phenomena comprising the collection of Dr. Percival Lowell, Director of the Lowell Observatory at Flagstaff, Ar.

Professor C. H. Currier, of Brown University, was at the museum all afternoon answering questions with regard to the 150 transparencies. The people seemed much interested in the exhibit, which was opened for the first time. It will be available to the public for several weeks. The photographs are on glass and are placed in a darkened room mounted in frames with powerful electric lamps behind them. They stand out in clear relief, delicate details being much more clearly shown than in those reproduced on paper.

The collection, probably the finest one of its kind in the world, was originally arranged for exhibition in the Boston Public Library. It has also been shown in the American Museum of Natural History in New York and at Princeton and Vassar Colleges.—*Popular Astronomy*, for November, 1916.

J. R. C.

DEATH OF PERCIVAL LOWELL.

With great regret we have learned that Professor Percival Lowell, recently elected an Honorary Fellow of the Royal Astronomical Society of Canada, died suddenly on Sunday, November 12, at Flagstaff, Arizona. A sketch of his life will appear in our next issue.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries.

QUERY.

I have been hoping that some professional astronomer would tell us amateurs how to find the dates of past and future phases of the moon. I believe there is an elementary method which we could understand.—George Sample, (Montreal).

ANSWER.

Not knowing any simple method except that of taking the lunation as $29\frac{1}{2}$ days and adding or subtracting multiples of this to the date of a given phase in order to determine the date of a like phase at any time in the future or in the past, respectively, the query was referred to Mr. R. M. Stewart, M.A., of the Dominion Observatory, Ottawa. His valuable reply follows:—

For a proper understanding of this subject it must be premised that the problem of the exact prediction of the moon's position for a given time is an extremely involved one, requiring

the computation of hundreds of terms; to realize its complexity it is sufficient to state that Hansen's "Tables de la Lune," which forms the basis of the modern computations, is a large volume containing over 400 pages of compactly printed tables. Since, however, its deviations from uniform motion are periodic, and since the vast majority of the terms are fortunately very small, it is possible to predict its position to a fair degree of approximation (for any length of time) from a consideration of only a few of the larger periodic terms. The problem is still further simplified when, as in the present case, we require only to know the interval between successive recurrences of the same phase, in which case the computation is comparatively elementary. The interval occupied by N complete lunations, correct to within two or three hours, may be expressed as follows:—

(1) From new moon to new moon or full moon to full moon

$$T = PN - 9\text{h } 52\text{m } [\sin(\phi + 25^\circ\ 49' \times N) - \sin\phi\ ] + 4\text{h } 9\text{m } [\sin(\phi' + 29^\circ\ 6\tfrac{1}{2}' \times N) - \sin\phi']\ ;$$

(2) From first quarter to first quarter or last quarter to last quarter

$$T = PN - 14\text{h } 53\text{m } [\sin(\phi + 25^\circ\ 49' \times N) - \sin\phi\ ] + 4\text{h } 9\text{m } [\sin(\phi' + 29^\circ\ 6\tfrac{1}{2}' \times N) - \sin\phi']\ ;$$

where T = the whole interval,

P = the synodic month = 29d 12h 44m 3s,

ϕ = the moon's mean anomaly (distance from perigee) for the initial date,

ϕ' = the sun's mean anomaly for the same date.

The above formula, though perhaps somewhat formidable in appearance to the non-mathematician, is in reality simple and easy of application. It may be noted that the first term alone ($T = PN$) will give a result never in error by more than about 36 hours.

For example, given the phases of the moon in January 1916, let it be required to find the time of full moon in December 1917. We find that full moon occurred on 1916 Jan. 19d 20h 29m Greenwich Mean Time (7 hours slow on Eastern Standard

Time); a simple preliminary computation shows immediately that the interval to full moon in December 1917 must be 24 lunations, or $N = 24$. Hence immediately $PN = 708\text{d } 17\text{h } 37\text{m}$, giving as a first approximation 1917 Dec. 28d 14h 6m G.M.T. To compute the correction to this date involved in the second and third terms of our formula we must have further data. From any astronomical ephemeris for 1916 we find the values of ϕ and ϕ' for our initial date to be 214° 16′ and 16° 54′, respectively; hence the quantities within the square brackets in the formula become respectively

$$[\sin 113^\circ 52' - \sin 214^\circ 16'] = .915 + .563 = 1.478,$$
$$\text{and } [\sin 355^\circ 30' - \sin 16^\circ 54'] = -.078 - .291 = -.369.$$

Hence $T = 708\text{d } 17\text{h } 37\text{m} - 14\text{h } 35\text{m} - 1\text{h } 32\text{m},$
$= 708\text{d } 1\text{h } 30\text{m},$
giving the date 1917 Dec. 27d 21h 59m G.M.T.

The actual date of the full moon in question is Dec. 27d 21h 52m G.M.T., the error of our prediction being only 7m; in general, however, as stated above, it can not be depended upon with certainty within two or three hours; the error of our first approximation was 16h 14m.

To decrease the limit of possible error to a value of a few minutes, a slight rearrangement of the formula and the addition of two more terms would suffice; the labor of computation would be considerably, though not prohibitively, increased.

To make this note entirely self-contained, for the benefit of those who have not access to an astronomical ephemeris and a table of sines of angles, the following short table is appended:

Angle	sine	Angle	sine	Angle	sine	Angle	sine
°		°		°		°	
0	·000	25	·423	50	·766	75	·966
5	·087	30	·500	55	·819	80	·985
10	·174	35	·574	60	·866	85	·996
15	·259	40	·643	65	·906	90	1·000
20	·342	45	·707	70	·940		

For an angle $A°$ between 90° and 180°, sine A = sine $(180° - A)$
For an angle $A°$ between 180° and 360°, sine A = — sine $(A - 180°)$
For an angle $A°$ greater than 360°, sine A = sine $(A - 360°)$
For 1916 Jan. 1d 0h G.M.T., $\phi = 327° 56'.3$
$\phi' = 358° 19'.1$
ϕ increases 13° 3′ 54″ per day.
ϕ' increases 59′ 8″ per day.

I do not think we can improve much on Mr. Stewart's reply when the phase is to be determined with reasonable accuracy; but quite incidentally a friend directed my attention to a letter which appeared in *The Spectator* (London) of October 7, 1916, written by George Forbes, of Kinnaird College, Pitlochrie. In it a method is given for finding out the moon's age on any date, though no explanation of the reason of the method is supplied. However, it is of very general interest and is reproduced here.

TO FIND THE AGE OF THE MOON ON ANY DAY IN ANY MONTH OF THE YEAR.

There is a day number, a month number and a year number, easily remembered. You add these together and whenever the number exceeds 30 you subtract 30. The result is the age of the moon on the day specified. 0 or 30 signifies new moon, 15 full moon, 7½ and 22½ the quarters.

(1) The day number is the day of the month.

(2) The month number is easily remembered if you write down the 12 initials of the months and read the corresponding numbers, in pairs, thus:—

J, F;	M, A;	M, J;	J, A;	S, O;	N, D.
0, 2;	0, 2;	2, 4;	4, 6;	7, 8;	9, 10.

This is the only real feat of memory required.

(3) The year number for any year is got by subtracting 1911 from the year and multiplying by 11 (subtracting 30 if necessary). The year number for 1911 is 0 and to this we add 11 for each year. This accidental coincidence of the numbers 11 and 1911 is a great help to the memory.

Take the date 1916, October 18.

The day number is	18
The month number is	8
The year number ($11 \times 5 - 30$) is	25
The sum is	51

The age of the moon is 21 days, got by subtracting 30. The answer is very seldom a day in error.

A RAINBOW ARC IN THE ZENITH.

Mr. A. F. Hunter, M.A., reports the following observation:

In the solar halo visible in Toronto, Saturday afternoon, Nov. 11th, 1916, two parhelia or "mock suns" were to be seen, with a prismatic arc displayed from time to time near the zenith. At 3 p.m. I first observed the halo, when the rainbow arc near the zenith and the "mock suns" were visible. The "mock suns" remained in sight almost continuously but the arc came and went several times, its last bright display being at 4.20 p.m. The fugitive nature of the arc was curious; it would seldom remain bright for more than two or three minutes at a time, once becoming bright for only the brief period of about a minute. The complete dependence of the arc on the "mock suns" was also noticeable; when the latter flared up brighter the arc would do the same. The very high altitude of the cirrus clouds that caused the halo was clearly shown by the fact that a dark, lower cloud would sometimes pass across a portion of the "mock suns," blotting out that portion for a short time. The whole phenomenon was due, of course, to minute snow crystals in the high cirrus clouds, and our first snowfall of the season on the ground occurred about 36 hours later. The chief interest of such halos is the information they give us about the high parts of the air, where no sounding kites or balloons can reach.

A DAYLIGHT METEOR.

Mr. Gustave Hahn reports that on November 7, 1916, at about 5 p.m., his two daughters, though in different parts of Toronto, saw a very bright meteor with a greenish tail pass from

north to south below the moon and about 1½ diameters away from it. If any others saw this meteor a report from them would be of interest.

A GREAT TELESCOPE FOR ARIZONA.

One of the recent bits of astronomical news is the statement that some anonymous friend has donated $60,000 to the University of Arizona, located at Tucson, for the erection of an astronomical observatory. According to the *Arizona Daily Star* of October 19, Professor A. E. Douglass aims to secure a 36-inch reflector which, with the admirable climatic conditions at Tucson, should give results of great value to astronomical science.

THE GREAT AURORA OF AUGUST 26TH.

Considerable additional information regarding the great auroral display of August 26 has been received and I had expected to publish it in this issue, but through lack of space it is held over until the next one. An interesting description of an aurora seen on September 30 is also held over.

C. A. C.

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